

**CHAPTER 2**

**EPA/NSF ETV**

**EQUIPMENT VERIFICATION TESTING PLAN**

**FOR THE REMOVAL OF SYNTHETIC ORGANIC CHEMICAL CONTAMINANTS**

**BY MEMBRANE FILTRATION PROCESSES**

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## LIST OF ABBREVIATIONS

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DIC	dissolved inorganic carbon
EPA	Environmental Protection Agency
PSTP	Product-Specific Test Plan
FTO	Field Testing Organization
GAC	granular activated carbon
HF	hollow fiber
HSD	homogeneous solution diffusion model
IMS	Integrated Membrane Systems
IOC	inorganic compounds
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF	microfiltration
MFI	modified fouling index
MTC	mass transfer coefficient
MWCO	molecular weight cut-off
NF	nanofiltration
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
PEG	polyethylene glycol
QA/QC	Quality Assurance/Quality Control
RO	reverse osmosis
SCADA	Supervisory Control and Data Acquisition
SDI	silt density index
SDWA	Safe Drinking Water Act
SOC	synthetic organic chemical
SW	surface water
TFC <sup>TM</sup>	thin-film composite
TOC	total organic carbon
TDS	total dissolved solids
UF	ultrafiltration
WTP	water treatment plant

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## **1.0 APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN**

This document is the ETV Testing Plan (Plan) for evaluation of membrane processes to be used within the structure provided by the “EPA/NSF ETV Protocol For Equipment Verification Testing For The Removal Of Synthetic Organic Chemical Contaminants: Requirements For All Studies”. This Plan is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing of membrane process equipment to achieve removal of synthetic organic chemical contaminants (SOCs).

In order to participate in the equipment verification process for membrane processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of a PSTP. The FTO shall clearly specify in its PSTP the SOCs targeted for removal and sampling program that shall be followed during Verification Testing. The PSTP should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the PSTP should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing program is to remove SOCs present in water supplies. Therefore, experimental design of the PSTP shall be developed so that relevant performance specifications for membrane process related to SOC removal are addressed. The Manufacturer shall establish a Statement of Performance Objectives (Section 3.0 General Approach) that is based upon removal of target SOCs from feedwaters. The experimental design of the PSTP shall be developed to address the specific Statement of Performance Objectives established by the Manufacturer. Each PSTP shall include all of the included tasks, Tasks 1 to 9.

## **2.0 INTRODUCTION**

Membrane processes are currently in use for a number of water treatment applications ranging from removal of inorganic constituents; total dissolved solids (TDS), total organic carbon (TOC), synthetic organic chemicals (SOCs), radionuclides and other constituents.

In order to establish appropriate operations conditions such as permeate flux, recovery, cross-flow velocity, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the Verification Testing. The need of

pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Pretreatment processes ahead of RO systems are generally required to remove particulate material and to ensure provision of high quality water to the membrane systems. For example, RO membranes cannot generally be applied to treatment of surface waters without pretreatment of the feedwater to the membrane system. For surface water applications, appropriate pretreatment, primarily for removal of particulate and microbiological species, must be applied as specified by the Manufacturer. In the design of the PSTP, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the RO membrane process. The stipulated feedwater pretreatment process(es) shall be employed for upstream of the membrane process at all times during the Equipment Verification Testing Program.

### 3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a State or accredited by a third-party organization (i.e., NSF) or the EPA for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Objectives the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The Statement of Performance Objectives must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. Two examples of Statements of Performance Objectives that may be verified in this testing are:

1. *This system is capable of achieving 98 percent removal of the SOC chlordane 60-day operation period at a flux of 15 gpm/sf (75 percent recovery; temperature between 20 and 25 °C) in feedwaters with chlordane concentrations less than 0.1 mg/L and total dissolved solids concentrations less than 500 mg/L.*
2. *This system is capable of producing a product water with a chlordane concentration less than 2 ~~ng~~mg/L during a 60-day operation period at a flux of 15 gpm/sf (75 percent recovery; temperature between 20 and 25 °C) in feedwaters with chlordane concentrations less than 0.1 mg/L and total dissolved solids concentrations less than 500 mg/L.*

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Objectives. For each Statement of Performance Objectives proposed by the FTO and the Manufacturer in the PSTP, the following information shall be provided:

- percent removal of the targeted SOC;

- rate of treated water production (i.e., flux);
- recovery;
- feedwater quality regarding pertinent water quality parameters;
- temperature;
- concentration of target SOC; and
- other pertinent water quality and operational conditions.

This ETV Testing Plan is broken down into 9 tasks, as shown in the Section 6.0, Overview of Tasks. These Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified under the ETV Program. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the PSTP. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan. All permeate flux values shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 77 °F or liters per square meter per hour (L/(m<sup>2</sup>-hr)) at 25 °C.

## **4.0 BACKGROUND**

This section provides an overview of the literature review related to SOC regulations, health effects and contaminant removal by membrane processes and membrane system design. These items will assist in recognizing the vast number of SOC contaminants, identifying the ability to remove SOC's from water supplies using membrane processes, defining membrane systems and describing the mechanisms that will help in qualifying and quantifying the removal efficiency of the membrane process tested.

### **4.1 Regulatory and Health Effects**

Since the passage of the Safe Drinking Water Act of 1974 (SDWA) requiring the establishment of recommended maximum contaminant levels (MCLs) for compounds that are deemed undesirable for consumption in public water supplies. Since that time there has been a growing awareness of the need for the control and removal of organic and inorganic contaminants from potable drinking water supplies. At the time of the passage of the SDWA of 1974, there were more than 12,000 chemical compounds known to be in commercial use. Many of these synthetic compounds are finding their way into potable water sources and ultimately into finished drinking water.

Within the past decade, several hundred specific organic chemicals have been identified in minute amounts in various drinking water supplies in the United States and abroad. Although at the present time the specific cause(s) of cancer are little understood, many of these commercially used organic compounds have been found to cause both acute and chronic adverse health effects in humans at various exposure levels. Therefore, in order to minimize risks to human health, the exposure levels to these compounds must be reduced to the lowest level possible that is both technologically and economically feasible.



The chronic health hazards associated with the presence of SOC's in drinking water have become a major concern of United States governmental agencies in more recent times. Consequently, contamination of potable water by SOC's is a significant national problem. Phase II and V of the SDWA have promulgated MCLs for 32 SOC's, of which 15 have been identified as carcinogenic. Appendix A lists the MCL, source of contamination and potential health effects for each regulated SOC. In addition, Appendix B lists the 46 SOC's proposed in the Drinking Water Regulations and Health Advisories and the Federal Register to be considered for regulation (USEPA 1996, 1997).

## 4.2 SOC Removal by Membrane Processes

This ETV Testing Plan is applicable to any pressure-driven membrane process used to achieve removal of SOC's. Furthermore, this testing plan is applicable to spiral-wound (SW) and hollow-fiber (HF) membrane configurations.

Membrane processes have been shown to be highly effective for the removal of SOC's. However, removal is a function of membrane mass transfer coefficients (MTCs), flux, recovery and feed concentration and will be expected to vary by membrane type. RO is also effective in producing a better overall quality of water.

Some advantages to the use of membrane processes for the removal of SOC's include:

- a small space requirement;
- removal of contaminant ions, dissolved solids, bacteria, and particles; and
- relative insensitivity to flow and TDS levels, and low effluent concentration.

Disadvantages include:

- higher capital and operating costs;
- higher level of pretreatment required;
- possible membrane fouling; and
- large reject streams.

Pressure-driven membrane processes are currently in use for a broad number of water treatment applications including the removal of pesticides and herbicides (i.e. SOC's), natural organic matter (NOM) which contributes to disinfection by-product formation, dissolved minerals, radionuclides and microbial contaminants such as *Giardia* and *Cryptosporidium*. Typically, higher pressure membrane applications such as nanofiltration (NF) and reverse osmosis (RO) are capable of removing SOC's, as well as ions contributing to hardness.

In contrast, low-pressure membrane processes, such as microfiltration (MF) and ultrafiltration (UF) are typically employed to provide a physical barrier for removal of microbial and particulate contaminants from drinking waters. However, the MF and UF membrane processes have not been shown to be effective for removal of SOC's unless another unit operation such as granular activated or powdered activated carbon is employed.

Suppliers of drinking water are subject to stringent government regulations for potable water quality regarding allowable pesticide and herbicide (i.e. SOC) concentrations. In particular, European standards require less than 0.1 µg/L for any one particular pesticide or herbicide and no greater than 0.5 µg/L for total pesticides and herbicides in drinking water. Many investigators have shown that RO/NF are effective techniques for pesticide and herbicide removal (Duranceau 1992, Camp 1995, Takigawa et.al. 1995, and Kruithof et.al. 1995). However, specific mechanisms underlying SOC rejection are largely unknown. In the paragraphs to follow, results from published accounts of pesticide reduction and the inferences regarding suspected mechanisms for removal are presented.

It has been demonstrated that membrane processes are effective for SOC removal (Duranceau and Taylor 1992, and Hofman et.al. 1993). However the mechanisms for SOC removal are still under investigation and are a subject of research. Intensive research efforts have investigated the associated rejection mechanisms for various pesticides and herbicides. Included among these mechanisms are:

- size exclusion,
- steric hindrance (shape)
- electrostatic repulsion
- adsorption
- matrix effects

In general, uncharged pesticide and herbicide rejection by RO/NF has been observed to decrease with decreasing molecular size (i.e. molecular weight or molecular cross-sectional area) (Kruithof et.al 1995, Chen et.al 1997, and Berg and Gimbel 1997). Since molecular weight and molecular cross-sectional area are not always directly related, distinguishing between these two parameters is an important consideration for determination of a size exclusion rejection mechanism for uncharged SOC (Berg and Gimbel 1997).

A study where NF treatability of a mixture of Elbe River (Germany) water and ground water with high sulfate and hardness content spiked with trace amounts of several SOC ( $C_{\text{feed}} \approx 1\mu\text{g/L}$ ) was conducted with both flat-sheet membrane films and spiral wound elements. Simazine, atrazine, terbutylazine, diuron, metazachlorine, TCA, and mecoprop composed the pesticide “cocktail” with which the surface water was spiked. Rejection of uncharged species terbutylazine, atrazine and simazine were reported to be in order of increasing size (Berg and Gimbel 1997). With the only difference between these species being the number of methyl groups, terbutylazine, with three methyl groups, was the highest rejected. Atrazine being the next largest in size was better rejected than simazine. Charged organic species were found to be significantly more rejected (predominately >85% for all membranes) by the negatively charged membranes than the polar SOC despite substantial size differences. However, a combination of both electrostatic repulsion and size was suspected to influence rejection as demonstrated by higher rejection of the SOC mecoprop as compared to its smaller charged counterpart TCA. By adjusting the feed pH to 3, added insight was provided by analyzing the rejections of mecoprop in its dissociated and undissociated form. These results showed greater rejection for the dissociated form of mecoprop. The rejection of the undissociated form was less than in its dissociated form and was comparable to the

rejection of uncharged diuron, which suggested a removal mechanism for these non-polar species to be that of steric hindrance.

Additional flat-sheet testing has been performed to evaluate the effects of matrix conditions upon pesticide rejection as applied to different membrane polymers. Reported evaluations (Chen et.al. 1997) have demonstrated general pesticide rejection in order of highest to lowest by membrane film to be polyamide, amine, and cellulose acetate based polymers. This conclusion resulted from an overall assessment of pesticides commonly used in both the U.S and Europe and their rejection in separate distilled, inorganic, organic and inorganic-organic matrices. These pesticides included simazine, atrazine, cyanazine, bentazone, diuron, DNOC, pirimicarb, metamitron, metribuzin, MCPA, mecoprop, and vinchlozolin at feed concentrations of approximately 10 µg/L. These investigators also demonstrated that solvent properties, inorganic versus organic in particular, did not have a large influence upon SOC rejection. The order of pesticide rejection by matrix listed in order of increasing to decreasing rejection of pesticides was reported to be inorganics, organics, distilled water and combination of inorganic and organic. Among all four matrices, overall rejection varied by less than 10%. While the flat-sheet film tests were able to detect significant performance differences among cellulose acetate versus thin-film composite membranes, “finite differences (using similar types of membranes) were not detected using cell tests because of variations in membrane films due to manufacturing or analytical limitations.”

SOC removal has also been the focus of attention for several Dutch Utilities. The PWN Water Supply Company of North Holland has studied cellulose acetate membrane polymers as applied to surface water for over 15 years (Camp 1995). Joint research between PWN and KIWA has shown thin-film composite (TFC) membranes to have better rejection properties than cellulose acetate (CA) membranes, but have the disadvantage of being more prone to fouling when surface water sources are used. As a single barrier, CA membranes were demonstrated to be inadequate for pesticide removal and they recommend granular activated carbon (GAC) post treatment (Kruithof et.al. 1995). However, at PWN, TFC membranes were shown to reject 90 to 95% of applied pesticide cocktails while CA membranes offered, as expected, less rejection of the SOC's. Moreover, chlorophenols were removed 25 to 90% with CA membranes. Experiments conducted in Leiden, the Netherlands also showed significant pesticide rejection. Using a 4-2-1 array equipped with six 4" single elements, Toray SU 710 L type membranes achieved 97 to greater than 99% rejection for all pesticides except 2,4 dichlorophenol (50%) and diuron (87%). Specifically, the highly rejected SOC's in this mixture were atrazine (99%), bentazone (>99%), DNOC (97%), and isoproturon (97%) with feed concentrations ranging from 5.1 to 6.3 µg/L. Bench-scale experiments conducted at PWN, which compared Hydranautics CPA2 and Toray SU 710 L, revealed comparable pesticide rejection for the two composite membranes. The least rejected SOC's were diuron and simazine of the trace concentration SOC mixture that included atrazine, bentazone, and DNOC. However, each individual SOC was rejected at or greater than 96% by both membranes except for diuron as treated by the Toray SU 710 L single element.

### **4.3 Membrane System Design Considerations**

Conventional NF or RO membrane systems consist of pretreatment, membrane processing and post-treatment. These processes are discussed in the following sections.

### 4.3.1 Pretreatment

The purpose of pretreatment is to control and minimize membrane fouling and reduce flux decline. The conventional pretreatment process consists of scale inhibitor (anti-scalant) and/or acid addition in combination with microfiltration. These pretreatment processes are used to control scaling and protect the membrane elements; they are required for conventional RO or NF membrane systems. The membranes can be fouled or scaled during operation. Fouling is caused by particulate materials such as colloids and organics that are present in the raw water attaching to the membrane surface, and will reduce the productivity of the membrane. Scaling is caused by the precipitation of a sparingly soluble salt within the membrane because of the solute concentration exceeding solubility. If a raw water is excessively fouling, additional or advanced pretreatment is required.

Flux decline indicated by a reduction in membrane process productivity can be a result of scaling, colloidal fouling, microbiological fouling and organic chemical fouling. Scaling can be approximated by chemical analysis and equilibrium calculations. Fouling indices can approximate colloidal fouling. Microbiological and organic chemical fouling can only be approximated at this time by pilot testing. These mechanisms should be recognized and understood, and are presented below in order to develop strategies to control flux decline.

**4.3.1.1 Scaling.** In an RO/NF membrane process, salts present in the feedwater are concentrated on the feed side of the membrane. This concentration process continues until saturation and salt precipitation (scaling) occurs. Scaling will reduce membrane productivity, and consequently, will limit the rate of water that may be recovered as permeate on a sustained basis. The maximum recovery is the recovery at which the limiting salt first begins to precipitate.

Limiting salts can be identified from the solubility products of potential limiting salts in the raw feedwater. Since ionic strength increases on the feed side of the membrane, the effect of ionic strength upon the solubility products must also be considered and taken into account for these calculations. Some limiting salts may be controlled via the addition of acid or scale inhibitor or both to the feedwater prior to membrane treatment. Typical sparingly soluble salts that may limit recovery in pressure-driven membrane processes include, but are not limited to,  $\text{CaCO}_3$ ,  $\text{CaSO}_4$ ,  $\text{BaSO}_4$ ,  $\text{SrSO}_4$ ,  $\text{CaF}_2$  and  $\text{SiO}_2$ .

As the feedwater passes through the membrane element from the feed side to the concentrate end of the membrane system, and the permeate water is removed, the feedwater salts become more concentrated. For instance, in a 75% recovery membrane system, the concentrate contains almost four times the concentration of salts that were present in the feedwater. This is called concentration polarization. Concentration polarization is the term used to describe the increased salt concentration that occurs at the surface of the membrane elements. As the permeate water passes through the membrane, the concentration of the rejected salts build up on the high-pressure side of the membrane surface. The amount of increased salt concentration over the bulk stream depends on how quickly the salts diffuse back into the bulk stream.

A high salt concentration at the membrane surface results in an increase in salt passage through the membrane. The increase in local salt concentration can lead to saturation of solution components resulting in precipitation on the membrane surface.

**4.3.1.2 Colloidal Fouling.** Colloidal fouling results from particles that exist in the influent which buildup on the surface of the membrane. The build-up forms a cake, which eventually is compressed and reduces flow through the membrane. Initially, cake formation does not significantly reduce productivity. However, after the cake compresses, the productivity decreases and the compressed cake must be removed. MF or UF membranes can be backwashed to remove the cake. However, spiral-wound RO and NF membranes require chemical cleaning to remove the cake. Advanced pretreatment processes such as cross-flow MF and multi-media filtration should control colloidal fouling.

**4.3.1.3 Microbiological Fouling.** Microbiological fouling results from biological growth in the membrane element, which results in a reduction in membrane productivity or an increase in pressure drop through an element. No reliable methods have been demonstrated for prediction of biofouling. Microbiological growth can occur in the feed spacers or on the membrane surface. Microbiological growth will occur in membranes but this growth does not always result in significant productivity loss. Advanced pretreatment processes may aid in the control of microbiological fouling.

**4.3.1.4 Chemical Fouling.** Chemical fouling results from the interaction of dissolved solutes in the feed stream with the membrane surface, which results in a reduction in membrane productivity. Chemical interaction between solute and the membrane surface will occur to some degree, but membrane productivity may not be reduced. Advanced pretreatment processes may aid in the control of chemical fouling.

#### **4.3.2 Advanced Pretreatment**

Advanced pretreatment would include unit operations that precede scaling control and cartridge filtration. By definition, unit operations that precede conventional pretreatment would be advanced pretreatment. Examples of advanced pretreatment would be coagulation/flocculation/sedimentation, oxidation followed by greensand filtration, continuous cross-flow microfiltration, multi-media filtration, and granular activated carbon (GAC) filtration.

#### **4.3.3 Membrane Processes**

The membrane process follows pretreatment. The majority of dissolved contaminants are removed in the membrane process. If the membrane scales or fouls, the productivity of the membrane system declines and eventually the membranes must be chemically cleaned to restore productivity. Cleaning frequencies for RO or NF systems average about 6 months when treating ground waters (Taylor et.al. 1990) and can be as low as 1 to 2 weeks when treating surface water with integrated membrane systems (IMSS).

UF or MF membranes as a stand alone process cannot remove SOC. However, powdered activated carbon (PAC) can be used for SOC adsorption followed by UF or MF to remove the PAC from the flow stream. MF and UF membranes are sieving controlled and do not have a low enough molecular weight cut-off (MWCO) range to reject many of the known SOC or inorganic compounds (IOC). RO and NF membranes can achieve significant SOC rejection because the MWCO of these membranes are low and many SOC cannot pass (Duranceau 1992). This is also the case with IOC and radionuclides. Although RO and NF have been shown to be among the most promising processes for SOC and IOC removal, not all SOC or IOC are rejected by these processes. RO and NF membranes use both sieving and diffusion mechanisms to reject SOC and IOC from drinking water and rejection will increase as the MW and charge of the contaminant increases. Typically, charged solutes and solutes with MWCOs greater than 200 mg/mmol are highly rejected by RO and NF.

UF and MF membranes do not affect corrosivity because inorganic ions are not removed; however, RO and NF do remove inorganic solutes from water, and this can impact the corrosivity of the permeate water.

#### **4.3.4 Post-Treatment**

Typical post-treatment unit operations can consist of disinfection, aeration, stabilization and storage. Aeration may be required to strip dissolved gases (Duranceau 1993). Stabilization may be required to produce a non-corrosive finished water since membrane permeate can be corrosive. Alkalinity recovery is an effective process for recovering dissolved inorganic carbon (DIC) in the permeate. Alkalinity can be recovered by lowering the pH prior to membrane filtration converting the alkalinity to CO<sub>2</sub>, and then raising the pH of the permeate in a closed system to recover dissolved CO<sub>2</sub> as alkalinity. Bypassing feedwater and blending it with membrane permeate is another way of stabilizing the finished water; however, blending would negate the benefit of the membrane treatment system to act as a physical barrier against microbial contaminants.

#### **4.3.5 Waste Disposal**

In addition to post treatment, the concentrate stream from the membrane processes must be treated and/or disposed of in some manner. Although membrane processes are at present often technically and economically well suited to produce drinking water, the disposal of membrane concentrate will become more difficult and more expensive because of increased regulation. Effective concentrate disposal methods depend on the concentrate water quality, local regulations and site-specific factors (AWWARF 1993). The handling and disposal of the wastes generated by treatment technologies removing SOC from drinking water pose concerns to the water supplier, to local and State governments and to the public at large. The potential handling hazards associated with SOC warrant the development of a viable membrane concentrate disposal method. Information regarding concentrate disposal options can be found in Membrane Concentrate Disposal (AWWARF 1993). The document investigates the application of regulations to the disposal of membrane concentrate. The document first addresses membrane concentrate and its characteristics, including the definitions and natures of

the wastes that are being generated. Then the disposal methods that are being regulated are addressed, including descriptions of how to dispose of the concentrate. Finally, the regulations and permits that apply to the various disposal options are addressed. The following are disposal options that must be approved by the State or local government prior to implementation of a waste disposal program.

#### Liquid Waste Disposal

- Direct discharge into storm sewers or surface water.
- Discharge into sanitary sewer.
- Deep well injection.
- Drying or chemical precipitation.

#### Solid Waste Disposal

- Temporary lagooning (surface impoundment).
- Disposal in landfill.
- Disposal without prior treatment.
  - a) With prior temporary lagooning.
  - b) With prior mechanical dewatering.
  - c) Application to land (soil spreading/conditioning).
- Disposal at State licensed waste facility.

## **5.0 DEFINITION OF OPERATIONAL PARAMETERS**

The following terms are presented here for subsequent reference in this test plan:

**Array** – An array is the series flow stream configuration of pressure vessels through a train defined by stages (4:2:1 array).

**Bulk Rejection** - Percent solute concentration retained by the membrane relative to the bulk stream concentration.

$$1 - \frac{C_p}{C_f}$$

where:

$C_f$  = feedwater concentration of specific constituent (mg/L)

$C_p$  = permeate concentration of specific constituent (mg/L)

**Bulk Solution** - The solution on the high-pressure side of the membrane that has a water quality between that of the influent and concentrate streams.

**Cleaning Frequency** - The loss or decrease of the mass transfer coefficient (MTC) for water measures membrane productivity over time of production. Membranes foul during operation. Constant production is achieved in membrane plants by increasing pressure. Cleaning is done when the pressure increases by 10 to 15 percent. Cleaning frequency (CF) and a measurement of productivity can be determined from the MTC decline.

$$CF = \frac{\Omega K_w}{\frac{dK_w}{dt}}$$

where:

CF = cleaning frequency (days)

$\Omega$  = acceptable rate of MTC loss

$dK_w/dt$  = rate of MTC decline (gsfd/psi-d)

**Concentrate ( $Q_c$ ,  $C_c$ )** - One of the membrane output streams that has a more concentrated water quality than the feed stream.

**Conventional RO/NF Process** - A treatment system consisting of acid and/or scale inhibitor addition for scale control, cartridge filtration, RO/NF membrane filtration, aeration, chlorination and corrosion control.

**Feed ( $Q_f$ ,  $C_f$ )** - Input stream to the membrane process after pretreatment.

**Feedwater** - Water introduced to the membrane module.

**Field Testing Organization (FDO)** - An organization qualified to conduct studies and testing of drinking water treatment systems in accordance with protocols and test plans. The role of the field testing organization is to complete the application on behalf of the Company; to enter into contracts with NSF, as discussed herein; and arrange for or conduct the skilled operation of equipment during the intense periods of testing during the study and the tasks required by the Protocol.

**Flux ( $F_w$ )** - Mass (lb/ft<sup>2</sup>-day) or volume (gal/ft<sup>2</sup>-day, gsfd, gfd) rate of transfer through membrane surface.

$$F_w = K_w [\Delta P - \Delta \Pi] = \frac{Q_p}{A}$$

where:

$F_w$  = water flux (M/L<sup>2</sup>·t)

$K_w$  = global water mass transfer coefficient (t<sup>-1</sup>)

$\Delta P$  = transmembrane pressure gradient (M/L<sup>2</sup>)

$\Delta \Pi$  = osmotic pressure gradient (M/L<sup>2</sup>)

$Q_p$  = permeate flow (L<sup>3</sup>/t)



A = membrane surface area ( $L^2$ )

**Fouling** - Reduction of productivity measured by a decrease in the temperature normalized water MTC.

**Fouling Indices** - Fouling indices are simple measurements that provide an estimate of the required pretreatment for membrane processes. Fouling indices are determined from membrane tests and are similar to mass transfer coefficients for membranes used to produce drinking water. Fouling indices can be quickly developed from simple filtration tests, are used to qualitatively estimate pretreatment requirements and possibly could be used to predict membrane fouling. The silt-density index (SDI), modified fouling index (MFI) and mini plugging factor index (MPFI) are the most common fouling indices. The SDI, MFI and the MPFI are defined using the basic resistance model, and are quantitatively related to water quality and NF membrane fouling.

Some approximations for required indices prior to conventional membrane treatment are given below (Sung et. al. 1994).

**Fouling Index Approximations for NF**

Fouling Index	Range
SDI	< 3
MFI	< 10 s/L <sup>2</sup>

**Silt-Density Index (SDI):** The SDI is the most commonly used test to predict a water's potential to foul a membrane by colloidal particles smaller than 0.45 microns. SDI is only a guide for pretreatment and is not an indication of adequate pretreatment. The SDI is a static measurement of resistance, which is determined by samples taken at the beginning and the end of the test. The SDI test is performed by timing the anaerobic hydraulic flow through a 47 mm diameter, 0.45 micron membrane filter at a constant pressure of 30 psi. The time required for 500 mL of the feedwater to pass through the filter is measured when the test is first initiated, and is also measured at time intervals of 5, 10, and 15 minutes after the start of the test. The value of the SDI is then calculated as follows (ASTM D-4189-82).

$$SDI = \left[ \frac{1 - \frac{t_i}{t_f}}{\frac{t_T}{t_f}} \right] (100\%)$$

where:

$t_i$  = time to collect initial 500 mL sample

$t_f$  = time to collect 500 mL sample at time  $t = T$

$t_T$  = total running time of the test; 5, 10, or 15 minutes.

If the index is below a value of 3 then the water should be suitable for reverse osmosis. If the SDI is below 3, the impact of colloidal fouling is minimized.

**Modified Fouling Index (MFI):** The MFI is determined using the same equipment and procedure used for the SDI, except that the volume is recorded every 30 seconds over a 15 minute filtration period (Schipper and Verdouw 1980). The development of the MFI is consistent with Darcy's Law in that the thickness of the cake layer formed on the membrane surface is assumed to be directly proportional to the filtrate volume. The total resistance is the sum of the filter and cake resistance. The MFI is defined graphically as the slope of an inverse flow versus cumulative volume curve as shown in the following equations:

$$\frac{dV}{dt} = \frac{\Delta P}{\mu} \frac{A}{(R_f + R_k)}$$

$$t = \frac{\mu V R_f}{\Delta P A} + \frac{\mu V^2 I}{2 \Delta P A^2}$$

$$\frac{1}{Q} = (a + MFI)V$$

where:

$R_f$  = resistance of the filter

$R_k$  = resistance of the cake

$I$  = measure of the fouling potential

$Q$  = average flow (liters/second)

$a$  = constant

Typically the cake formation, build-up and compaction or failure can be seen in three distinct regions on a MFI plot. The regions corresponding to blocking filtration and cake filtration represent productive operation, whereas compaction would be indicative of the end of a productive cycle.

**Hollow-Fiber** – Fine hollow fibers of membrane material are extruded in either a cellulose triacetate or a polyamide. The ends of the fibers are sealed in an epoxy block connected with the outside of the housing. The epoxy block is cut to allow the flow from the inside of the fine fibers to the other side of the epoxy block, where it is collected. The pressurized feedwater passes across the outside of the fibers. Pure water permeates the fibers and is collected at the end of the element.

The hollow-fiber housings are capable of holding a large quantity of fibers, this allowing a single element to produce a large permeate flow rate. Hollow-fiber elements are typically used for seawater desalination, and for brackish-water applications

**Influent** - Input stream to the membrane array after the recycle stream has been blended with the feed stream. If there is no concentrate recycle then the feed and influent streams are identical.

**Mass Transfer Coefficient (MTC) ( $K_w$ )** - Mass or volume unit transfer through membrane based on driving force (gfd/psi).

$$K_w = \frac{Q_p}{A(\Delta P - \Delta \Pi)}$$

where:

$K_w$  = global water mass transfer coefficient ( $t^{-1}$ )

$\Delta P$  = transmembranic pressure gradient ( $M/L^2$ )

$\Delta \Pi$  = osmotic pressure gradient ( $M/L^2$ )

$Q_p$  = permeate flow ( $L^3/t$ )

$A$  = membrane surface area ( $L^2$ )

**Membrane Element** - A single membrane unit containing a bound group of spiral wound or hollow-fiber membranes to provide a nominal surface area for treatment.

**Membrane Molecular Weight Cutoff Determination** - The membrane molecular weight cutoff (MWCO) of membranes is commonly used to characterize membrane rejection capability. Membrane MWCO is typically determined by measuring the rejection of different molecular weight nonionic polymers. Solute rejection is defined as:

$$\% \text{ Solute Rejection} = \left( 1 - \frac{C_p}{C_f} \right) (100\%)$$

Given the narrow molecular weight bands of polyethylene glycol (PEG) solutions, these nonionic random coil polymers can be applied to membranes for MWCO estimation. Although the percent PEG rejection varies by manufacturer, 80 to 90 percent PEG rejection has been used. Neither the percent rejection nor the material is fixed except by membrane manufacturer. The standard molecular weight solutions can be measured as TOC and correlated to PEG concentration. This correlation can then be applied for assessment of PEG rejection by the membrane and subsequent MWCO determination.

**Membrane Productivity** - Membrane productivity will be assessed by the rate of mass transfer coefficient ( $MTC_w$ ) decline over time of operation. As flux declines, a constant product can be achieved by increasing pressure to maintain a constant flux.

Net Driving Pressure (NDP): The net driving pressure (NDP) is calculated using the influent, concentrate and permeate pressure.

$$NDP = \left[ \frac{(P_f + P_c)}{2} \right] - P_p - \Delta \Pi$$

where:

NDP = net driving pressure for solvent transport across the membrane (psi, bar)

$P_f$  = feedwater pressure to the feed side of the membrane (psi, bar)

$P_c$  = concentrate pressure on the reject side of the membrane (psi, bar)

$P_p$  = permeate pressure on the treated water side of the membrane (psi, bar)

$\Delta\pi$  = osmotic pressure (psi)

Osmotic Pressure Gradient ( $\Delta\pi$ ):: The term osmotic pressure gradient refers to the difference in osmotic pressure generated across the membrane barrier as a result of different concentrations of dissolved salts. In order to determine the NDP, the osmotic pressure gradient must be estimated from the influent, concentrate and permeate TDS.

$$\Delta\pi = \left( \left[ \frac{(TDS_f + TDS_c)}{2} \right] - TDS_p \right) \left( \frac{1 \text{ psi}}{100 \frac{\text{mg}}{\text{L}}} \right)$$

where:

$TDS_f$  = feedwater total dissolved solids (TDS) concentration (mg/L)

$TDS_c$  = concentrate TDS concentration (mg/L)

$TDS_p$  = permeate TDS concentration (mg/L)

Mass Transfer Coefficient ( $MTC_w$ ): The  $MTC_w$  is calculated by dividing the permeate flow by the membrane surface area.

$$F_w = \frac{Q_p}{A} = (MTC_w)(NDP)$$

From this the  $MTC_w$  can be calculated. However, given the relationship between temperature and the viscosity of water, flux should be normalized to a standard temperature condition (25°C). These relationships should be provided by the membrane manufacturer and used to normalize the flux data set as shown below.

$$MTC_{w, 25^\circ C} = \frac{F_{w, 25^\circ C}}{NDP}$$

Temperature Adjustment for Flux Calculation: If manufacture does not specify a temperature correction equation the following equation may be used so that water production can be compared on an equivalent basis.

$$F_{w, 25^\circ C} = F_{w, T^\circ C} \left( 1.03^{(25^\circ C - T^\circ C)} \right)$$

Recovery: Recovery should also be calculated using the permeate and influent flow.

$$R = \frac{Q_p}{Q_i}$$

Using the above equations the  $MTC_w$ , normalized flux and recovery for each stage and the system can be calculated for each set of operational data and plotted as a function of cumulative operating time.

**Package Plant** - A complete water treatment system including all components from the connection to the raw water(s) intake through discharge to the distribution system.

**Permeate ( $Q_p$ ,  $C_p$ )** - The membrane output stream that has convected through the membrane.

$$Q_p C_p = Q_f C_f - Q_c C_c$$

**Permeate** - Water produced by the membrane process.

**Permeate Flux** - The average permeate flux is the flow of permeate divided by the surface area of the membrane. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

where:

$J_t$  = permeate flux at time  $t$  (gfd,  $L/(h \cdot m^2)$ )

$Q_p$  = permeate flow (gpd, L/h)

$S$  = membrane surface area ( $ft^2$ ,  $m^2$ )

It should be noted that only gfd and  $L/(h \cdot m^2)$  shall be considered acceptable units of flux for this testing plan.

**Pressure Vessel** - A single tube or housing that contains several membrane elements in series.

**Product-Specific Test Plan (PSTP)** - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF ETV Protocol(s) and Test Plan(s) that apply to a specific make and model of equipment.

**Raw** - Input stream to the membrane process prior to any pretreatment.

**Recovery** - The recovery of feedwater as permeate water is given as the ratio of permeate flow to feedwater flow:

$$\% \text{ System Recovery} = \left[ \frac{Q_p}{Q_f} \right] (100\%)$$

where:

$Q_f$  = feedwater flow to the membrane (gpm, L/h)

$Q_p$  = permeate flow (gpm, L/h)

**Recycle Ratio ( $r$ )** - The recycle ratio represents the ratio of the total flow of water that is used for cross-flow and the net feedwater flow to the membrane. This ratio provides an idea of the recirculation

pumping that is applied to the membrane system to reduce membrane fouling and specific flux decline.

$$\text{Recycle Ratio} = \left[ \frac{Q_r}{Q_f} \right]$$

where:

$Q_f$  = feedwater flow to the membrane (gpm, L/h)

$Q_r$  = recycle hydraulic flow in the membrane element (gpm, L/h)

**Rejection (mass)** – The mass of a specific solute entering a membrane system that does not pass through the membrane.

$$\left( 1 - \frac{Q_p C_p}{Q_f C_f} \right)$$

**Scaling Control** - Controlling precipitation or scaling within the membrane element requires identification of a limiting salt, acid addition for prevention of  $\text{CaCO}_3$  and/or addition of a scale inhibitor. The limiting salt determines the amount of scale inhibitor or acid addition. A diffusion controlled membrane process will concentrate salts on the feed side of the membrane. If excessive water is passed through the membrane, this concentration process will continue until a salt precipitates and scaling occurs. Scaling will reduce membrane productivity and consequently recovery is limited by the allowable recovery just before the limiting salt precipitates. The limiting salt can be determined from the solubility products of potential limiting salts and the actual feed stream water quality. Ionic strength must also be considered in these calculations as the natural concentration of the feed stream during the membrane process increases the ionic strength, allowable solubility and recovery.

Calcium carbonate scaling is commonly controlled by sulfuric acid addition however sulfate salts are often the limiting salts. Commercially available scale inhibitors can be used to control scaling by complexing the metal ions in the feed stream and preventing precipitation. Equilibrium constants for these scale inhibitors are not available which prevents direct calculation. However some manufacturers provide computer programs for estimating the required scale inhibitor dose for a given recovery, water quality and membrane. The following are general equations for the solubility products and ionic strength approximations.

**Solubility Product:** Calculation of the solubility product of selected sparingly soluble salts will be important exercise for the test plan in order to determine if there are operational limitations caused by the accumulation of limiting salts at the membrane surface. Text book equilibrium values of the solubility product should be compared with solubility values calculated from the results of experimental Verification Testing, as determined from use of the following equation:

$$K_{sp} = \tilde{a}_A^x [A^{y-}]^x \tilde{a}_B^y [B^{x+}]^y$$

where:

$K_{sp}$  = solubility product for the limiting salt being considered

$\gamma$  = free ion activity coefficient for the ion considered (i.e., A or B)

[A] = molal solution concentration of the anion A for sparingly soluble salt  $A_xB_y$

[B] = solution concentration of the anion B

x, y = stoichiometric coefficients for the precipitation reaction of A and B

**Mean Activity Coefficient:** The mean activity coefficients for each of the salt constituents may be estimated for the concentrated solutions as a function of the ionic strength:

$$\log \tilde{\gamma}_{A,B} = -0.509 Z_A Z_B \sqrt{i}$$

where:

$\gamma$  = free ion activity coefficient for the ion considered (i.e., A or B)

$Z_A$  = ion charge of anion A

$Z_B$  = ion charge of cation B

$\mu$  = ionic strength

**Ionic Strength:** A simple approximation of the ionic strength can be calculated based upon the concentration of the total dissolved solids in the feedwater stream:

$$i = (2.5 \cdot 10^{-5})(TDS)$$

where:

$\mu$  = ionic strength

TDS = total dissolved solids concentration (mg/L)

**Solute** - The dissolved constituent (mg/L) in a solution or process stream.

**Solute Rejection** - Solute rejection is controlled by a number of operational variables that must be reported at the time of water sample collection. Bulk rejection of a targeted inorganic chemical contaminant may be calculated by the following equation.

$$\% \text{ Solute Rejection} = \left[ \frac{C_f - C_p}{C_f} \right] (100\%)$$

where:

$C_f$  = feedwater concentration of specific constituent (mg/L)

$C_p$  = permeate concentration of specific constituent (mg/L)

**Solvent** - A substance, usually a liquid such as water, capable of dissolving other substances.

**Solvent and Solute Mass Balance** - Calculation of solvent mass balance is performed to verify the reliability of flow measurements through the membrane. Calculation of solute mass balance across the

membrane system is performed to estimate the concentration of limiting salts at the membrane surface.

$$Q_f = Q_p + Q_c$$

$$Q_f C_f = Q_p C_p + Q_c C_c$$

where:

$Q_f$  = feedwater flow to the membrane (gpm, L/h)

$Q_p$  = permeate flow (gpm, L/h)

$Q_c$  = concentrate flow (gpm, L/h)

$C_f$  = feedwater concentration of specific constituent (mg/L)

$C_p$  = permeate concentration of specific constituent (mg/L)

$C_c$  = concentrate concentration of specific constituent (mg/L)

**Specific Flux** - At the conclusion of each chemical cleaning event and upon return to membrane operation, the initial condition of transmembrane pressure shall be recorded and the specific flux calculated. The efficiency of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficiency achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow an evaluation of irreversible fouling. Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task.

Percent Recovery of Specific Flux: The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux ( $F_{sf}$ ) and the initial specific flux ( $F_{si}$ ) measured for the subsequent run.

$$\% \text{ Recovery of Specific Flux} = \left[ 1 - \frac{F_{sf}}{F_{si}} \right] (100\%)$$

where:

$F_{sf}$  = Specific flux (gfd/psi, L/(h-m<sup>2</sup>)/bar) at end of run (final)

$F_{si}$  = Specific flux (gfd/psi, L/(h-m<sup>2</sup>)/bar) at beginning of run (initial).

Percent Loss of Original Specific Flux: The loss of original specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run ( $F_{si}$ ) divided by the original specific flux ( $F_{sio}$ ), as measured at the initiation of the first filtration run in a series.

$$\% \text{ Loss of Original Specific Flux} = \left[ 1 - \frac{F_{si}}{F_{sio}} \right] (100\%)$$

**Spiral-Wound** - Spiral-wound membrane elements are constructed of flat sheet membranes folded and glued on three edges to create several membrane envelopes. The open edge of the each envelope is glued to a central collection pipe with perforations to allow water from inside the envelope to pass into the pipe. The envelopes are spun around the central collection pipe. Layered inside each envelope is a



thin layer of fabric that prevents the envelope from sealing itself off when the outside of the envelope is exposed to high pressure. The fabric allows the passage of permeate water to the center collection tube.

The feed water enters the end of the spiral-wound element and moves across the surface of the rolled-up membrane envelopes. Spacers between the envelopes promote turbulence so that pure water permeates the envelopes, any salts left behind will diffuse back into the bulk solution. Inside the envelope the pressure is near atmospheric, whereas the pressure on the feedwater side can be as high as 1,000 psi. The pressure differential drives the pure water into the membrane envelope. In the envelope the permeate passes through fabric material and finds its way into the central collection pipe. The water in the collection pipe travels to the end where it either enters the collection tube of another element, or is transferred to the permeate port of the end cap of the housing.

**Stage** – A stage is the configuration of an array.

**Train** – A train is a parallel flow stream through the membrane system. For instance a 5 MGD membrane system may be comprised of five 1 MGD trains.

**Verification Statement** - A written document that summarizes a final report reviewed and approved by NSF on behalf of the USEPA or directly by the USEPA.

**Water System** - The water system that operates using water treatment equipment to provide potable water to its customers.

## 6.0 OVERVIEW OF TASKS

This Plan is applicable to the testing of water treatment equipment utilizing membrane processes. Testing of membrane processes will be conducted by a NSF-qualified Field Testing Organization that is selected by the Manufacturer. Water quality analyses will be performed by a state-certified or third party-, or EPA-qualified analytical laboratory. This Plan provides objectives, work plans, schedules, and evaluation criteria for the required tasks associated with the equipment testing procedure.

The following is a brief overview of the tasks that shall be included as components of the Verification Testing Program and PSTP for removal of SOC's.

- **Task 1: Characterization of Raw Water** – Obtain chemical, biological and physical characterization of the raw water. Provide a brief description of the watershed that provides the raw water to the water treatment plant.
- **Task 2: Membrane Productivity** - Demonstrate operational conditions for the membrane equipment; permeate water recovery achieved by the membrane equipment; and rate of flux decline observed over an extended membrane process operation.
- **Task 3: Finished Water Quality** – Evaluate the water quality produced by membrane processes as it relates to raw water quality and operational conditions.

- **Task 4: Cleaning Efficiency** – Evaluate the effectiveness of chemical cleaning to the membrane system and confirm that the Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity.
- **Task 5: Operations and Maintenance (O&M)** - Develop an O&M manual for each system submitted. The O&M manual shall characterize membrane process design, outline a membrane process cleaning procedure or procedures, and provide a concentrate disposal plan.
- **Task 6: Data Collection and Management** – Establish an effective field protocol for data management between the Field Testing Organization and NSF.
- **Task 7: Quality Assurance / Quality Control (QA/QC)** – Develop a QA/QC protocol for Verification Testing. This is an important item that will assist in obtaining an accurate measurement of operational and water quality parameters during membrane equipment Verification Testing.
- **Task 8: Cost Evaluation** - Develop capital and O&M costs for the submitted NF membrane technology and equipment.

## 7.0 TESTING PERIODS

The required tasks of the ETV Testing Plan (Tasks 1 through 9) are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. The schedule for equipment monitoring during the 60-day testing period shall be stipulated by the FTO in the PSTP, and shall meet or exceed the minimum monitoring requirements of this testing plan. The FTO shall ensure in the PSTP that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the “EPA/NSF ETV Protocol For Equipment Verification Testing For The Removal Of Synthetic Organic Chemical Contaminants: Requirements For All Studies”. The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein.

For membrane process treatment equipment, factors that can influence treatment performance include:

- Feedwaters with high seasonal concentrations of inorganic constituents and TDS. These conditions may increase finished water concentrations of inorganic chemical contaminants and may promote precipitation of inorganic materials in the membrane;
- Feedwaters with variable pH; increases in feedwater pH may increase the tendency for precipitation of sparingly soluble salts in the membrane module and may require variable strategies in anti-scalant addition and pH adjustment;
- Cold water, encountered in winter or at high altitude locations;
- High concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasonal periods;
- High turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single 60-day period during the Verification Testing Program. Membrane testing conducted beyond the required 60-day testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During the testing periods, evaluation of cleaning efficiency and finished water quality can be performed concurrent with membrane operation testing procedures.

During the time intervals between equipment verification runs, the water treatment equipment may be used for production of potable water. If the equipment is being used for the production of potable water, routine operation for water production is expected. The operating and water quality data collected and furnished to the local regulatory agency should also be supplied to the NSF-qualified FTO.

## **8.0 TASK 1: CHARACTERIZATION OF RAW WATER**

### **8.1 Introduction**

A characterization of raw water quality is needed to determine if the concentrations of SOC's or other raw water contaminants are appropriate for the use of NF membrane processes. The feedwater quality can influence the performance of the equipment as well as the usefulness of testing results to readers of the verification report.

### **8.2 Objectives**

One reason for performing a raw water characterization is to obtain at least one-year of historical raw water quality data from the raw water source. The objective is to:

- demonstrate seasonal effects on the concentration of SOC's; and
- develop maximum and minimum concentrations for the contaminant.

If historical raw water quality is not available, a raw water quality analysis of the proposed feedwater shall be performed prior to equipment Verification Testing.

### **8.3 Work Plan**

The characterization of raw water quality is best accomplished through the performance of laboratory testing and the review of historical records. Sources for historical records may include municipalities, laboratories, USGS (United States Geological Survey), USEPA, and local regulatory agencies. If historical records are not available preliminary raw water quality testing shall be performed prior to equipment Verification Testing. The specific parameters of characterization will depend on the NF membrane process that is being tested. The following characteristics should be reviewed and documented:

- |                |              |           |
|----------------|--------------|-----------|
| • Specific SOC | • True Color | • Nitrate |
| • Temperature  | • Chloride   | • Sodium  |

- pH
- TDS/Conductivity
- Total Hardness
- Calcium Hardness
- Total Organic Carbon
- Total Alkalinity
- Turbidity
- Fluoride
- Sulfate
- Ammonia
- Iron
- Manganese
- Silica
- Barium
- Potassium
- Strontium
- Phosphate
- SDI
- MFI

Data collected should reflect seasonal variations in the above data if applicable. This will determine variations in water quality parameters that will occur during Verification Testing. The data that is collected will be shared with NSF so that the FTO can determine the significance of the data for use in developing a test plan. If the raw water source is not characterized, the testing program may fail, or results of a testing program may not be considered acceptable. A description of the raw water source should also be included with the feedwater characterization. The description may include items such as:

- size of watershed;
- topography;
- land use;
- nature of the water source; and
- potential sources of pollution.

#### **8.4 Schedule**

The schedule for compilation of adequate water quality data will be determined by the availability and accessibility of historical data. The historical water quality data can be used to determine the suitability of NF membrane processes for the treatment for the raw source water. If raw water quality data is not available, a preliminary raw water quality testing should be performed prior to the Verification Testing of the NF membrane equipment.

#### **8.5 Evaluation Criteria**

The feedwater quality shall be evaluated in the context of the Manufacturer's Statement of Performance Objectives for the removal of SOC's. The feedwater should challenge the capabilities of the chosen equipment, but should not be beyond the range of water quality suitable for treatment by the chosen equipment. For NF membrane processes, a complete scan of water quality parameters may be required in order to determine limiting salt concentrations, necessary for establishing pretreatment criteria.

## **9.0 TASK 2: MEMBRANE PRODUCTIVITY**

### **9.1 Introduction**

The removal of SOC<sub>s</sub> from drinking water supplies is accomplished by NF membrane filtration. The effectiveness of NF membrane processes for SOC removal will be evaluated in this task. Membrane mass transfer coefficient, flux and recovery will be evaluated in this task. After installation of a NF membrane, compaction and ripening of the membrane will cause a characteristic flux decline with time until the membrane stabilizes. After this initial flux decline, the rate of flux decline will be used to demonstrate membrane performance for the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the Manufacturer in terms of a temperature-corrected flux (normalized flux) value (e.g., gsf<sub>d</sub> at 77°F or L/(m<sup>2</sup>hr) at 25°C) before the initiation of the Program.

Flux decline is a function of water quality, membrane type, configuration and operational conditions. In establishing the range of operation for the membrane performance evaluations, limiting salt information should be used to define the run scenarios. The run conditions should include operating scenarios, which approach and exceed these projected limits. Subsequent water quality analysis will allow for assessment of the degree of saturation of the sparingly soluble salts in the final concentrate. The degree of saturation of the salts should then be compared to resulting membrane productivity decline. Table 9.1 presents an example of membrane pretreatment data required to provide baseline conditions and assist in evaluating membrane productivity.

Some Manufacturers may wish to employ the NF membrane process with a pretreatment process in order to reduce flux decline and improve removal of SOC<sub>s</sub>. Any pretreatment included in the membrane treatment system that is designed for removal of SOC<sub>s</sub> shall be considered an integral part of the membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes.

### **9.2 Experimental Objectives**

The objectives of this task are to demonstrate:

- Operational conditions for the membrane equipment;
- Permeate water recovery achieved by the membrane equipment; and
- Rate of flux decline observed over extended membrane process operation.

Raw water quality shall be measured prior to system operation and then monitored every two weeks during the 60-day testing period at a minimum. It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the Manufacturer, as it pertains to permeate flux and transmembrane pressure, and SOC removal.

### 9.3 Work Plan

Determination of ideal membrane operating conditions for a particular water may require as long as one year of operation. For this task the Manufacturer shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the membrane treatment system. The Manufacturer shall evaluate flux decline. The Manufacturer shall also determine the limiting salt and identify possible foulants and scalants, and use this for performance evaluation for their particular membrane equipment. The set of operating conditions shall be maintained for the 60-day testing period (24-hour continuous operation). The Manufacturer shall specify the primary permeate flux at which the equipment is to be verified. Additional operating conditions can be verified in separate 60-day testing periods.

After set-up and “shakedown” of membrane equipment, membrane operation should be established at the flux condition to be verified. Testing of additional operational conditions could be performed by extending the number of 60-day testing periods beyond the initial 60-day period required by the Verification Testing Program at the discretion of the Manufacturer and their designated FTO.

Additional 60-day periods of testing may also be included in the Verification Testing Plan in order to demonstrate membrane performance under different feedwater quality conditions. For membrane processes, extremes of feedwater quality (e.g., low temperature, high TOC concentration, variable SOC concentrations, high SDI and high turbidity) are the conditions under which membranes are most prone to fouling and subsequent failure. At a minimum the performance of the NF membrane equipment relative to SOC removal shall be documented during those periods of variable feedwater conditions. The Manufacturer shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 60-day testing period, as required above for each additional set of operating conditions.

The testing runs conducted under this task shall be performed in conjunction with finished water quality and if applicable, cleaning efficiency. With the exception of additional testing periods conducted at the Manufacturer’s discretion, no additional membrane test runs are required for performance of cleaning efficiency and finished water quality. A continuous yearlong evaluation, although not required, may be of benefit to the Manufacturer for verification of long term trends.

#### 9.3.1 Operational Data Collection

Measurement of membrane feedwater flow and permeate flow (recycle flow where applicable) and system pressures shall be collected at a minimum of 3 eight-hour shifts per day. Table 9.2 is an example of a daily operational data sheet for a two-stage membrane system. This table is presented for informational purposes only. Figure 9.1 presents the sample locations for the daily operational data sheet. The actual forms will be submitted as part of the test plan and may be site-specific. Measurement of feedwater temperature to the membranes shall be made along with these three daily measurements in order to provide data for normalizing flux with respect to temperature

Water quality should be analyzed from the same locations identified for TDS in Table 9.2 prior to start-up and then twice a month for the parameters identified in Table 9.3, except for each SOC, which will be monitored weekly. Power costs for operation of the membrane equipment (pumping requirements, chemical usage, etc.) shall also be closely monitored and recorded by FTO during the 60-day testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements: pumping requirements; size of pumps; name-plate; voltage; current draw; power factor; peak usage; etc. In addition, measurement of power consumption and chemical consumption shall be quantified by recording such items as day tank concentration, daily volume consumption and unit cost of chemicals.

### **9.3.2 Feedwater Quality Limitations**

The characteristics of feedwaters used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the membrane flux and recovery data for each period. Accurate reporting of such feedwater characteristics are critical for the Verification Testing Program, as these parameters can substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions. The following criteria and trends should also be presented in the Verification Testing Program:

- Evaluation criteria and minimum reporting requirements.
- Plot graph of SOC removed over time for each 30-day period of operation.
- Plot graph of NDP over time for each 30-day period of operation.
- Plot graph of TDS over time for each 30-day period of operation.
- Plot graph of  $F_{w25^{\circ}\text{C}}$  over time for each 30-day period of operation.
- Plot graph of  $\text{MTC}_w$  over time for each 30-day period of operation.
- Plot graph of recovery over time for each 30-day period of operation.

**TABLE 9.1: NF Membrane Pretreatment Data**

<b>Foulants and Fouling Indices of the Feedwater Prior to Pretreatment</b>	
Alkalinity (mg/L of CaCO <sub>3</sub> )	
Ca Hardness (mg/L of CaCO <sub>3</sub> )	
LSI	
Dissolved iron (mg/L)	
Total iron (mg/L)	
Dissolved aluminum (mg/L)	
Total aluminum (mg/L)	
Fluoride (mg/L)	
Phosphate (mg/L)	
Sulfate (mg/L)	
Calcium (mg/L)	
Barium (mg/L)	
Strontium (mg/L)	
Reactive silica (mg/L as SiO <sub>2</sub> )	
Turbidity (NTU)	
SDI	
<b>Pretreatment Processes Used Prior to Nanofiltration or Reverse Osmosis</b>	
Pre-filter listed pore size (µm)	
Type of acid used	
Acid concentration (units)	
mL of acid per L of feed	
Type of scale inhibitor used	
Scale inhibitor concentration (units)	
mL of scale inhibitor per L of feed	
Type of coagulant used	
Coagulant dose (mg/L)	
Type of polymer used during coagulation.	
Polymer dose (mg/L)	

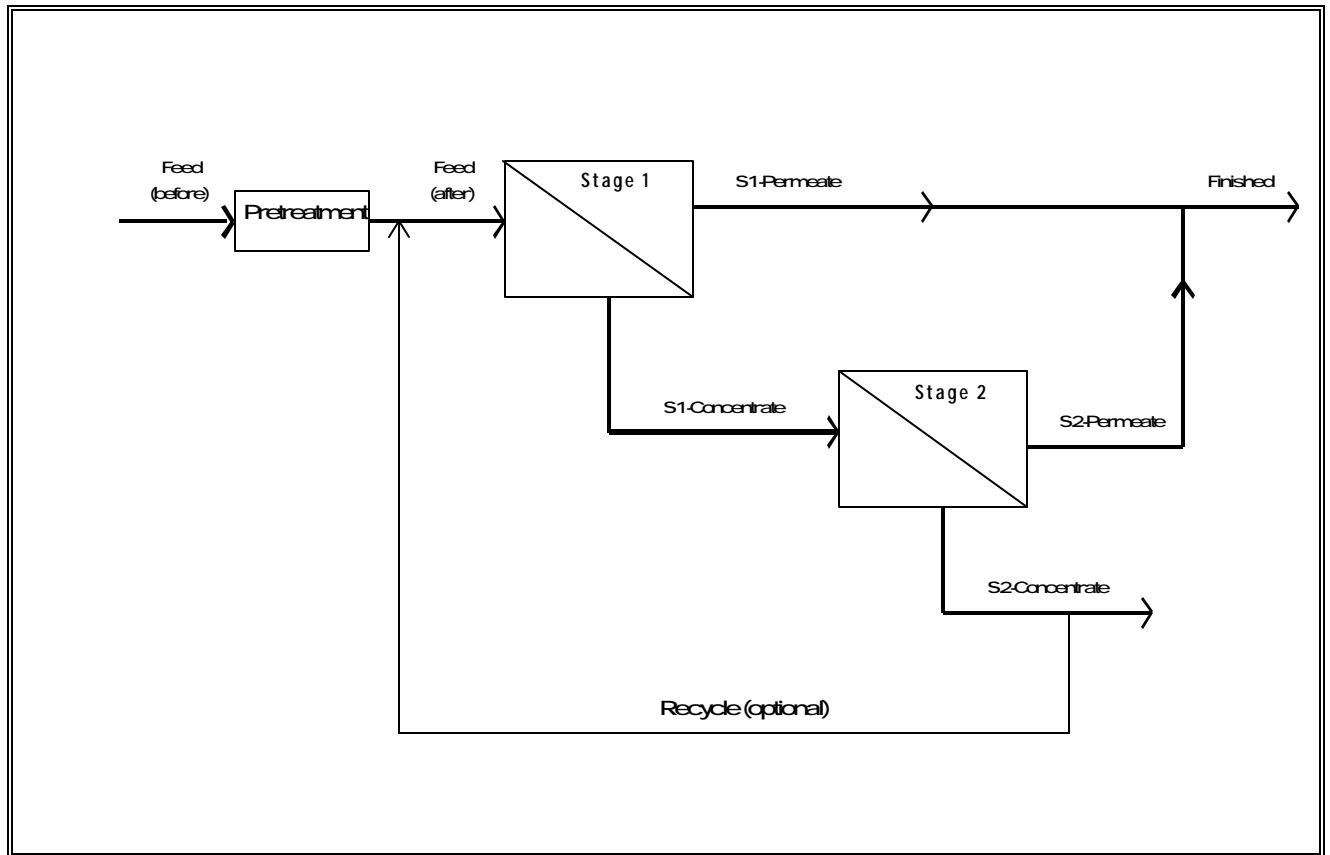


**TABLE 9.2: Daily Operations Log Sheet for a Two-Stage Membrane System**

**Date:**

Parameter	Shift 1	Shift 2	Shift 3
<b>Time</b>			
<b>Initial</b>			
<b>Feed</b>			
$Q_{\text{feed}}$ (gpm)			
$\text{TDS}_{\text{feed}}$ (before pretreatment) (mg/L)			
$\text{TDS}_{\text{feed}}$ (after pretreatment) (mg/L)			
$P_{\text{feed}}$ (psi)			
$\text{pH}_{\text{feed}}$ (before pretreatment)			
$\text{pH}_{\text{feed}}$ (after pretreatment)			
$T_{\text{feed}}$ (°C)			
<b>Permeate - Stage 1</b>			
$Q_{\text{p-S1}}$ (gpm)			
$\text{TDS}_{\text{p-S1}}$ (mg/L)			
$P_{\text{p-S1}}$ (psi)			
<b>Concentrate - Stage 1</b>			
$Q_{\text{c-S1}}$ (gpm)			
$\text{TDS}_{\text{c-S1}}$ (mg/L)			
$P_{\text{c-S1}}$ (psi)			
$T_{\text{c-S1}}$ (°C)			
<b>Permeate - Stage 2</b>			
$Q_{\text{p-S2}}$ (gpm)			
$\text{TDS}_{\text{p-S2}}$ (mg/L)			
$P_{\text{p-S2}}$ (psi)			
<b>Concentrate - Stage 2</b>			
$Q_{\text{c-S2}}$ (gpm)			
$\text{TDS}_{\text{c-S2}}$ (mg/L)			
$P_{\text{c-S2}}$ (psi)			
<b>Finished</b>			
$Q_{\text{fin}}$ (gpm)			
$\text{TDS}_{\text{fin}}$ (mg/L)			
Recovery ( $Q_{\text{fin}}/Q_{\text{feed}}$ ) (%)			
<b>Recycle</b>			
$Q_{\text{recycle}}$ (gpm)			

**FIGURE 9.1: Sample Locations for a Two-Stage Membrane Process**



**TABLE 9.3: Operating and Water Quality Data Requirements for Membrane Processes**

<b>Parameter</b>	<b>Frequency and Importance for Sampling</b>
Feedwater Flow	3 * Daily (1)
Permeate Water Flow	3 * Daily (1)
Concentrate Water Flow	3 * Daily (1)
Feedwater Pressure	3 * Daily (1)
Permeate Water Pressure	3 * Daily (1)
Concentrate Water Pressure	3 * Daily (1)
List Each Chemical Used, And Dosage	Daily Data Or Monthly Average (1)
Hours Operated Per Day	Daily (1)
Hours Operator Present Per Day	Monthly Average (2)
Power Costs (Kwh/Million Gallons)	Monthly (2)
Independent check on rates of flow	Weekly (1)
Independent check on pressure gages	Weekly (2)
Verification of chemical dosages	Monthly (1)
SOCs	1, Weekly
Temperature	3 * Daily (1)
pH	3 * Daily (1)
TDS/Conductivity	3 * Daily (1)
Turbidity	Every two weeks (1)
True Color	Every two weeks (1)
Total Organic Carbon	Every two weeks (1)
UV Absorbance (254 nm)	Every two weeks (1)
Total Alkalinity	Every two weeks (1)
Total Hardness	Every two weeks (1)
Calcium Hardness	Every two weeks (1)
Sodium	Every two weeks (1)
Chloride	Every two weeks (1)
Iron	Every two weeks (1)
Manganese	Every two weeks (1)
Sulfate	Every two weeks (1)
Fluoride	Every two weeks (1)
Silica	Every two weeks (1)
Ammonia	Every two weeks (1)
Potassium	Every two weeks (1)
Strontium	Every two weeks (1)
Barium	Every two weeks (1)
Nitrate	Every two weeks (1)
TTHM	Every two weeks (2)
THAA	Every two weeks (2)
TOX	Every two weeks (2)

1 = Required    2 = Desired But Not Necessary

## **10.0 TASK 3: FINISHED WATER QUALITY**

### **10.1 Introduction**

Water quality data shall be collected for the raw and finished water as provided previously in Table 9.3. (Note, in some instances sampling concentrate water quality may be required because detection limits may be too low for a specified parameter.) At a minimum, the required sampling shall be one sampling at start-up and two sampling events per month while raw water samples are collected. Water quality goals and target removal goals for the membrane equipment should be proved and reported in the PSTP.

### **10.2 Objectives**

The objective of this task is to verify the Manufacturer's performance objectives. Table 9.3 presented a list of the minimum number of water quality parameters to be monitored during equipment Verification Testing has been provided in this document. The actual water quality parameters selected for testing and monitoring shall be stipulated in the PSTP.

### **10.3 Work Plan**

The PSTP shall identify the treated water quality objectives to be achieved in the Statement of Performance Objectives of the equipment to be evaluated in the Verification Testing Program. The PSTP shall also identify in the Statement of Performance Objectives the specific SOC's that shall be monitored during equipment testing. The Statement of Performance Objectives prepared by the PSTP shall indicate the range of water qualities and operating conditions under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the drinking water treatment systems participating in the SOC Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. Although the SOC Verification Testing Plan is oriented towards removal of SOC's, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. A state-certified or third-party- or EPA-qualified analytical laboratory shall perform analysis of the remaining water quality parameters. Representative methods to be used for measurement of water quality parameters in the field and lab are identified in Table 10.1. The analytical methods utilized in this study for on-site monitoring of raw and finished water qualities are described in Quality Assurance/ Quality Control (QA/QC). Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

**TABLE 10.1: Water Quality Analytical Methods**

Parameter	Standard Method <sup>1</sup>	EPA Method <sup>2</sup>
<b><u>Phase II SOCs</u></b>		
2,4,5-TP (Silvex)	6640 B	515.1; 515.2; 555
2,4-D (Formula 40, Weedar 64)	6640 B	515.1; 515.2; 555
Acrylamide		
Alachlor (Lasso)		505; 507; 525.2; 508.1
Aldicarb	6610 B	531.1
Aldicarb sulfone	6610 B	531.1
Aldicarb sulfoxide	6610 B	531.1
Atrazine		505; 507; 508.1; 525.2
Carbofuran (Furadan 4F)	6610 B	531.1
Chlordane	6410 B; 6630 B,C	505; 508; 508.1; 525.2
Dibromochloropropane (DBCP, Nemaflow))	6210 C,D; 6230 D; 6231 B	504.1; 551
Ethylene dibromide (EDB, Bromofume)		504.1; 551
Heptachlor (H-34, Heptox)	6410 B; 6630 B, C	505; 508; 508.1; 525.2
Heptachlor epoxide	6410 B; 6630 B, C	505; 508; 508.1; 525.2
Lindane	6630 B	505; 508; 508.1; 525.2
Methoxychlor (DMDT, Marlate)	6630 B	505; 508; 508.1; 525.2
Pentachlorophenol	6410 B; 6420 B; 6640 B	515.1; 515.2; 525.2; 555
Polychlorinated biphenyls (PCBs, Aroclor)	6410 B; 6630 C	505; 508; 508A
Toxaphene	6410 B; 6630 B, C	505; 508; 525.2
<b><u>Phase V SOCs</u></b>		
Adipate (diethylhexyl)		506; 525.2
Dalapon	6640 B	515.1; 552.1
Dichloromethane		
Dinoseb	6640 B	515.1; 515.2; 555
Dioxin		1613
Diquat		549.1

**TABLE 10.1: Water Quality Analytical Methods (Cont.)**

<b>Parameter</b>	<b>Standard Method <sup>1</sup></b>	<b>EPA Method <sup>2</sup></b>
Endothall		548.1
Endrin	6410 B; 6630 B, C	505; 508; 508.1; 525.2
Glyphosate	6651 B	547
Hexachlorobenzene	6040 B; 6410 B	505; 508; 508.1; 525.2
Hexachlorocyclopentadiene	6410 B	505; 508; 508.1; 525.2
Oxamyl (Vydate)	6610 B	531.1
Phthalate		506; 525.2
Phenanthrene (PAH)	6040 B; 6410 B; 6440 B	525.1; 550; 550.1
Picloram	6640 B	515.1; 515.2; 555
Simazine		505; 507; 508.1; 525.2
Trichlorobenzene (1,2,4-)	6040 B; 6210 D; 6220 C; 6230 D; 6410 B	
Trichloroethane (1,1,2,-)	6040 B; 6210 B, C, D; 6220 C; 6230 B, C, D	
<b><u>Physical Parameters</u></b>		
Temperature	2550 B	
pH	4500-H <sup>+</sup> B	150.1; 150.2
Conductivity	2510 B	120.1
Total Dissolved Solids	2540 C	
Total Suspended Solids	2540 D	
Turbidity	2130 B; Method 2	180.1
Dissolved Oxygen	4500-O B	
<b><u>Organics</u></b>		
True color	2120 B	
Total Organic Carbon	5310 C	
UV <sub>254</sub> absorbance	5910 B	
Total Trihalomethanes (TTHMs)	6232 B	524.3
Total Haloacetic Acids (THAAs)	6251 B	552.1

**TABLE 10.1: Water Quality Analytical Methods (Cont.)**

<b>Parameter</b>	<b>Standard Method <sup>1</sup></b>	<b>EPA Method <sup>2</sup></b>
Total Organic Halogens (TOX)	5320 B	
<b><u>Inorganics</u></b>		
Total Alkalinity	2320 B	
Total Hardness	2340 C	
Calcium Hardness	3500-Ca <sup>+2</sup> D	
Sodium	3111 B	200.7
Chloride	4110 B; 4500-Cl D	300.0
Iron	3111 D; 3113 B; 3120 B	200.7; 200.8; 200.9
Manganese	3111 D; 3113 B; 3120 B	200.7; 200.8; 200.9
Sulfate	4110 B; 4500-SO <sub>4</sub> <sup>-2</sup> C, D, F	300.0; 375.2
Fluoride	4110 B; 4500-F <sup>-</sup> B, C, D, E	300.0
Silica (total and dissolved)	3120 B; 4500-Si D, E, F	200.7
Ammonia, NH <sub>3</sub>	4500-NH <sub>3</sub> B, C, D	350.3
Potassium	3111 B; 3500-K C, D, E	200.7
Strontium	3111 B; 3500-Sr C,D,E	200.7
Barium	3111 D; 3113 B; 3120 B	200.7; 200.8
Nitrate	4110 B; 4500-NO <sub>3</sub> <sup>-</sup> D, F	300.0; 353.2

1) AWWA, Standard Methods for the Examination of Water and Wastewater, 20<sup>th</sup> Edition, 1999.

2) EPA, Methods and Guidance for Analysis of Water, EPA 821-C-97-001, April 1997.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the state-certified or third-party- or EPA-qualified laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain-of-custody requirements, as specified by the analytical lab.

## **10.4 Analytical Schedule**

### **10.4.1 Removal of SOC's**

During the steady-state operation of each membrane testing period, SOC mass balances shall be performed on the membrane feed, permeate and concentrate water in order to determine the SOC removal capabilities of the membrane system.

#### **10.4.2 Feed and Permeate Water Characterization**

At the beginning of each membrane testing period, the raw water, permeate and in some cases concentrate water shall be characterized at a single set of operating conditions by measurement of the water quality parameters identified in Table 9.3.

#### **10.4.3 Water Quality Sample Collection**

Water quality data shall be collected at regular intervals during each period of membrane equipment testing. The minimum monitoring frequency for the required water quality parameters is once at start-up and weekly for SOC's and every two weeks for the remaining water quality parameters. The water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling. Analyses for organic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, in order to provide the maximum degree of comparability between water quality analytes.

No monitoring of microbial populations shall be required in this Equipment Verification Testing Plan. However, the Manufacturer may include optional monitoring of indigenous microbial populations to demonstrate removal capabilities.

#### **10.4.4 Raw Water Quality Limitations**

The characteristics of feedwaters encountered during each 60-day testing period shall be explicitly stated. Accurate reporting of such raw water characteristics such as those identified in Table 9.3 are critical for the Verification Testing Program, as these parameters can substantially influence membrane performance.

### **10.5 Evaluation Criteria and Minimum Reporting Requirements**

- Removal or reduction of SOC's.
- Water quality and removal goals specified by the Manufacturer.

## **11.0 TASK 4: CLEANING EFFICIENCY**

### **11.1 Introduction**

There are certain types of foulant scales that pose an immediate threat to the operational integrity of a membrane process. Examples of scale include calcium carbonate scale and silica or sulfate scale.

Should scaling or fouling occur during or following the test runs, the membrane equipment shall require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the fouling frequency of the membrane during each specified test period. In the case where the membrane does not fully reach the operational criteria for fouling as specified by the Manufacturer, chemical cleaning shall be performed after the 30 days of operation, with a record made of the operational conditions before and after cleaning.



The membrane treatment process will be optimized for sustained production under high product water recovery and solvent flux. Productivity goals shall be stated in the PSTP in terms of productivity decline and/or operational time.

Either normalized flux decline or solvent mass transfer (MTC<sub>w</sub>) reduction will determine productivity decline. The use of the normalized MTC<sub>w</sub> for productivity decline would eliminate the need for constant system pressure for productivity decline determination. Chemical cleaning of the membranes will be performed as necessary for the removal of reversible foulants per Manufacturer specifications. These cleaning events are to be documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system. The cleaning solutions should also be analyzed to determine which constituents may have adsorbed or precipitated onto the membrane surface during cleaning. This may also prove useful for establishing the mechanism of removal for some SOC<sub>s</sub>.

## **11.2 Experimental Objectives**

The objective of this task is to evaluate the effectiveness of chemical cleaning to the membrane systems. The intent of this task is to confirm that standard Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the Manufacturer recommendations. This task is considered a "proof of concept" effort, not an optimization effort.

## **11.3 Work Plan**

The membrane systems may become fouled during the membrane test runs. These fouled membranes shall be utilized for the cleaning assessments herein. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer, which will vary according to identified foulants or scale. After each chemical cleaning of the membranes, the system shall be restarted and then returned to the flux condition being tested.

The Manufacturer shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- quantities and costs of cleaning chemicals
- hydraulic conditions of cleaning
- duration of each cleaning step
- chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed

## **11.4 Recommended Disposal Procedures**

Methods of disposal of membrane concentrate include, but are limited to the following:

- Public works wastewater plant;

- Deep well injection; or
- Discharge to a surface water with accordance to the National Pollutant Discharge Elimination System (NPDES) Program.

However SOC's are considered a potentially hazardous waste and the effluent must be monitored since it is concentrated. The concentrate disposal may require other State and/or Federal permits. In addition, a description of all cleaning equipment and its operation shall be described and included in the O&M manual.

## **11.5 Analytical Schedule**

### **11.5.1 Sampling**

The pH of each cleaning solution shall be determined and recorded during various periods of the chemical cleaning procedure. Conductivity and turbidity should also be used to monitor flush periods.

### **11.5.2 Operational Data Collection**

Flow and pressure data shall be collected before system shutdown due to membrane fouling; flow and pressure data shall also be collected after chemical cleaning.

## **12.0 TASK 5: OPERATIONS AND MAINTENANCE MANUAL**

An operations and maintenance (O&M) manual for the membrane system to be tested for SOC removal shall be included in the Verification Testing evaluation.

### **12.1 Objectives**

The objective of this task is to provide an O&M manual that will assist in operating, troubleshooting and maintaining the membrane system performance. The O&M manual shall:

- characterize the membrane process design;
- outline a membrane process cleaning procedure or procedures; and
- provide a concentrate disposal plan.

The concentrate disposal plan must be approved by the State in question for permanent installation. A fully developed concentrate disposal plan would be required because of the SOC's that have been concentrated in the waste stream. Criteria for evaluation of the equipment's O&M Manual shall be compiled and then evaluated and commented upon during verification by the FTO. An example is provided in Table 12.1.

Each specific test plan will include a list of criteria for evaluating O&M information. This shall be compiled and submitted for evaluation by EPA, NSF and technical peer reviewers. An example is provided in Table 12.2. The purpose of this O&M information is to allow utilities to effectively choose

a technology that their operators are capable of operating, and provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

**TABLE 12.1: OPERATIONS & MAINTENANCE MANUAL CRITERIA -  
NF Membrane Process Systems**

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**MAINTENANCE:**

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The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- flow meters
- pressure gauges
- pumps
- motors
- valves
- chemical feeders
- mixers

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- membranes
  - pressure vessels
  - piping
- 

**OPERATION:**

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The manufacturer should provide readily understood recommendation for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:

Chemical feeders:

- calibration check
- settings and adjustments - how they should be made
- dilution of chemicals and scale inhibitors - proper procedures

Monitoring and observing operation:

- mass balance calculations
- recovery calculation

**TABLE 12.1: OPERATIONS & MAINTENANCE MANUAL CRITERIA -  
NF Membrane Process Systems (continued)**

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**OPERATION (continued):**

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Monitoring and observing operation (continued):

- pressure losses

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- flux decline;
- no raw water (feedwater) flow to plant;
- when the water flow rate through the equipment can not be measured;
- no chemical feed;
- automatic operation (if provided) not functioning;
- no electric power; and
- sand or silt entrainment (such as plugging of prefilters).

The following are recommendations regarding operability aspects of membrane processes. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program. During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects.

- are chemical feed pumps calibrated?
- are flow meters present and have they been calibrated?
- are pressure gauges calibrated?
- are pH meters calibrated?
- are TDS or conductivity meters calibrated?
- can cleaning be done automatically?
- can membrane seals be easily replaced?
- does remote notification occur (alarm) when pressure increases > 15% or flow drops > 15%?

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The reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Operating Conditions and Treatment Equipment Performance, in the Membrane Process Test Plan.

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**TABLE 12.2: Requirements for Maintenance and Operability of NF Membrane Process Systems**

MAINTENANCE INFORMATION		
Equipment	Maintenance Frequency	Replacement Frequency
Membranes		
Pumps		
Valves		
Motors		
Mixers		
chemical mixers		
water meters		
pressure gauges		
cartridge filters		
Seals		
Piping		

OPERABILITY INFORMATION: (rank from 1 (easy) to 3 (difficult), or N/A)	
Operation Aspect	Response
Chemical feed pumps calibration	
Flow meters calibration	
Pressure gauges calibration	
pH meters calibration	
TDS or conductivity meters calibration	
Cleaning	
Replacement of membrane seals	
Measurement and control of flux decline	

**Notes:**

## 12.2 O&M Work Plan

Descriptions for pretreatment, membrane process, and post-treatment to characterize the membrane system unit process design shall be developed. Membrane processes shall include the design criteria and membrane element characteristics. Examples of information required relative to the membrane design criteria and element characteristics are presented in Tables 12.3 and 12.4, respectively.

**TABLE 12.3: NF Membrane Plant Design Criteria Reporting Items**

<b>Parameter</b>	<b>Value</b>
Number of trains	
Number of stages	
Stage configuration	
Number of pressure vessels in stage 1	
Number of pressure vessels in stage 2	
Number of elements per pressure vessel	
Recovery per stage (%)	
Recovery for system (%)	
Design flow (gpm)	
Design temperature (°C)	
Design flux (gsfd)	
Surface area per element (ft <sup>2</sup> )	
MTC <sub>w</sub> (gsfd/psi)	
Maximum flow rate to an element (gpm)	
Minimum flow rate to an element (gpm)	
Pressure loss per element (psi)	
Pressure loss in stage entrance and exit (psi)	
Feed stream TDS (mg/L)	
SOC rejection (%) *	

\* Specify SOC name(s), chemical and trade name(s).

**TABLE 12.4: NF Membrane Element Characteristics**

Membrane manufacturer			
Membrane module model number			
Size of element used in study (e.g. 4" x 40")			
Active membrane area of element used in study			
Active membrane area of an equivalent 8" x 40" element			
Purchase price for an equivalent 8" x 40" element (\$)			
Molecular weight cutoff (Daltons)			
Membrane material / construction			
Membrane hydrophobicity (circle one)	Hydrophilic	Hydrophobic	
Membrane charge (circle one)	Negative	Neutral	Positive
Design pressure (psi)			
Design flux at the design pressure (gfd)			
Variability of design flux (%)			
MTC <sub>w</sub> (gfd/psi)			
Standard testing recovery (%)			
Standard testing pH			
Standard testing temperature (°C)			
Design cross-flow velocity (fps)			
Maximum flow rate to the element (gpm)			
Minimum flow rate to the element (gpm)			
Required feed flow to permeate flow rate ratio			
Maximum element recovery (%)			
Rejection of reference solute and conditions of test (e.g. solute type and concentration)			
Variability of rejection of reference solute (%)			
Spacer thickness (ft)			
Scroll width (ft)			
Acceptable range of operating pressures			
Acceptable range of operating pH values			
Typical pressure drop across a single element			
Maximum permissible SDI			
Maximum permissible turbidity (NTU)			
Chlorine/oxidant tolerance			
Suggested cleaning procedures			

Note: Some of this information may not be available, but this table should be filled out as completely as possible for each membrane tested.

The membrane treatment process will be optimized for sustained production under high product water recovery and solvent flux. Productivity goals shall be stated in the PSTP.

Productivity decline will be indicated and signaled by either normalized flux decline or normalized solvent mass transfer ( $MTC_w$ ) reduction. Normalized means that the flux has been adjusted for temperature and pressure. The use of the normalized  $MTC_w$  for productivity decline would eliminate the need for constant system pressure for productivity decline determination.

Chemical cleaning of the membranes will be performed as necessary for the removal of reversible foulants per manufacturer specifications. These cleaning events are to be documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system. The cleaning solutions could also be analyzed for determining which constituents may have adsorbed or precipitated onto the membrane surface. Analysis of cleaning solutions can be coupled with mass balances on the same solutes monitored during operation to determine solute accrual in membrane elements. This may prove useful for establishing the mechanism of removal for some SOCs. A cleaning efficiency evaluation is described in Section 11.0.

The potential handling hazards associated with SOCs warrant the development of a viable membrane concentrate disposal method and safety program. Provisions for concentrate disposal from the system must be developed as part of the work plan.

## **13.0 TASK 6: DATA COLLECTION AND MANAGEMENT**

### **13.1 Introduction**

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets, in addition to manual recording of operational parameters for the membrane processes on a daily basis.

### **13.2 Objectives**

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for verification purposes. Chain-of-Custody protocols will be developed and adhered to.

### **13.3 Work Plan**

#### **13.3.1 Data Handling Work Plan**

The following protocol has been developed for data handling and data verification by the FTO. In addition to daily operational data sheets, a Supervisory Control and Data Acquisition (SCADA) system could be used for automatic entry of testing data into computer databases. Specific parcels of the computer database for operational and water quality parameters should then be downloaded by manual importation into electronic spreadsheets. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters.



In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of membrane process operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

Field testing operators shall record data and calculations by hand in laboratory notebooks for three eight-hour shifts per day. (Daily measurements shall be recorded on specially prepared data log sheets as appropriate. Table 9.2 presents an example of a daily log sheet). The laboratory notebook shall provide copies of each page. The original notebooks shall be stored on-site; the copied sheets shall be forwarded to the project engineer of the FTO at least once per week during the 60-day testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include

- descriptions of the and test runs;
- names of visitors; and
- descriptions of any problems.

Such descriptions shall be provided in addition to experimental calculations and other items.

### **13.3.2 Data Management**

The database for the project shall be set up in the form of custom designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the field laboratory analysis notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time.

Following data entry, the spreadsheet shall be printed and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hardcopies and corrected on the screen, and then the corrected recorded calculations will also be checked and confirmed. The field testing operator or engineer performing the data entry or verification step shall initial each step of the verification process.

Each experiment (e.g. each membrane process test run) shall be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third-party- or EPA-qualified laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the FTO. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

### **13.3.3 Statistical Analysis**

For the analytical data obtained during Verification Testing, 95 percent confidence intervals shall be calculated by the FTO for selected water quality parameters. The specific Plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval

calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. When presenting the data, maximum, minimum, average and standard deviation should be included.

Calculation of confidence intervals shall not be required for equipment performance obtained during the equipment Verification Testing Program. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period.

## **14.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL**

### **14.1 Introduction**

Quality assurance and quality control (QAQC) of the operation of the membrane process equipment and the measured water quality parameters shall be maintained during the Equipment Verification Testing Program.

### **14.2 Experimental Objectives**

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

### **14.3 QA/QC Work Plan**

Equipment flow rates should be calibrated and verified and verification recorded on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate, and into a flow stream that is operating at the expected flow rate. This will provide correct chemical concentrations in the flow stream. In-line monitoring equipment such as flow meters, etc. shall be checked as indicated below to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

When collecting water quantity data, all system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the finished water flow rate by the “bucket test” method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stopwatch. This will allow for a direct check of the system flow measuring devices.

Mass balances will be performed on the system for water quality parameters measured in the feed, permeate and concentrate streams. This will enable an additional quality control check on the accuracy and reliability of the analyzed data. SOC in particular will be analyzed in each process stream.

However, the difficulty in measuring some low level SOC's may limit the mass balance to be calculated based on feed and concentrate. Mass balances may provide insight into the mechanism for rejection of individual SOC's. For example, mass balances showing incomplete recovery for a particular SOC may suggest possible adsorption onto the membrane surface.

#### **14.3.1 Daily QA/QC Verifications**

- Chemical feed pump flow rates (check and verify components)
- On-line conductivity meters (check and verify components)
- On-line pH meters (standardize and recalibrate)
- On-line turbidimeter flowrates (verified volumetrically over a specific period of time)
- On-line turbidimeter readings checked against a properly calibrated bench model

#### **14.3.2 QA/QC Verifications Performed Every Two Weeks**

- Chemical feed pump flow rates (verify volumetrically over a specific time period)
- On-line conductivity meters (recalibrate)
- On-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings)

#### **14.3.3 QA/QC Verifications Performed Every Testing Period**

- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)

### **14.4 On-Site Analytical Methods**

Use of either bench-top field analytical equipment will be acceptable for the Verification Testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. However, standard and uniform calibration and standardization techniques that are approved should be employed. Table 10.1 lists Standard Methods and EPA methods of analysis.

#### **14.4.1 pH**

Analysis for pH shall be performed according to *Standard Method 4500-H<sup>+</sup>*. A three-point calibration of the pH meter used in this study will be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. Therefore, measure the pH under a continuous stream of sample by placing the tip of the probe in the sample container allowing the sample to overflow the container while the probe reaches

equilibrium. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss with the atmosphere.

#### **14.4.2 Turbidity**

Turbidity analyses shall be performed according to Standard Method 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. Grab samples shall be analyzed using a bench-top turbidimeter; readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of Verification Testing and on a weekly basis using primary turbidity standards of 0.1, 0.5 and 3.0 NTU. Secondary turbidity standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

**14.4.2.1 Bench-Top Turbidimeters.** The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

When cold water samples cause the vial to fog and prevent accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

**14.4.2.2 In-Line Turbidimeters.** In-line turbidimeters may be used during verification testing and must be calibrated as specified in the manufacturer's operation and maintenance manual. It will be necessary to periodically verify the in-line readings using a bench-top turbidimeter; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-

needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

#### **14.4.3 Temperature**

Readings for temperature shall be conducted in accordance with *Standard Method 2550*. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

#### **14.4.4 Dissolved Oxygen**

Analysis for dissolved oxygen shall be performed on raw ground water samples according to *Standard Method 4500-O* using an iodometric method or the membrane electrode method. The techniques described for sample collection must be followed very carefully to avoid causing changes in dissolved oxygen during the sampling event. Sampling for dissolved oxygen does not need to be coordinated with sampling for other water quality parameters, so dissolved oxygen samples should be taken at times when immediate analysis is going to be possible. This will eliminate problems that may be associated with holding samples for a period of time before the determination is made.

If the sampling probe is not mounted such that the probe is continuously exposed to the process stream, then care must be taken when measuring the dissolved oxygen concentration. For best results, collect the dissolved oxygen sample with minimal agitation and measure the dissolved oxygen concentration immediately. If possible, measure the dissolved oxygen under a continuous stream of sample by placing the tip of the probe in the sample container, allowing the sample to overflow the container while the probe reaches equilibrium (usually less than 5 minutes).

### **14.5 Chemical Samples Shipped Off-Site for Analysis**

The analytical methods that shall be used during testing for chemical samples that are shipped off-site for analyses are described in the section below.

#### **14.5.1 Organic Samples**

Samples for analysis of total organic carbon (TOC), UV<sub>254</sub> absorbance, and dissolved organic carbon (DOC) shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4 °C to the analytical laboratory within 24 hours of sampling. These samples shall be preserved in accordance with Standard Method 5010 B. Storage time before analysis shall be minimized, according to Standard Methods.

### **14.5.2 Inorganic Samples**

Inorganic chemical samples shall be collected and preserved in accordance with Standard Methods or EPA-approved methods. The samples shall be refrigerated at approximately 2 to 8°C. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of analysis.

### **14.5.3 SOC Analysis**

Analysis of SOC's requires a trained analyst using sophisticated instrumentation. Only state-certified or third party- or EPA-accredited laboratories shall analyze SOC samples that are collected during Initial Operations and Verification Testing. As stated in the "EPA/NSF ETV Protocol For Equipment Verification Testing For The Removal Of Synthetic Organic Chemical Contaminants: Requirements For All Studies," approved methods for some SOC's may not be available, and for these SOC's, a proposed, peer-reviewed method may be used.

There are many approved methods for analyzing Phase II and Phase V SOC's. Depending on the laboratory, gas chromatography (GC) or high performance liquid chromatography (HPLC) methods can be used to analyze SOC's. For both methods, the equipment is highly specialized and proper operation of these instruments requires a skilled laboratory technician.

Mass spectrometry is not required for all SOC's, however it is recommended for SOC identification. Retention times relative to the internal standard can also be used to identify SOC's. Either peak height or peak area can be used to determine the SOC concentrations.

SOC's shall be analyzed with an internal standard similar in analytical behavior and not affected by the matrix for QA/QC. An appropriate surrogate standard shall also be used during SOC analysis. Data pertaining to the internal and surrogate standards shall be reported with the SOC concentrations of the samples being analyzed. A method blank shall also be prepared and analyzed by the state-certified or third party- or EPA-accredited laboratory to verify minimal contamination in the laboratory.

At least three standards shall be used to develop the standard curve for SOC quantification and these three standards shall be extracted and analyzed (by GC or HPLC) on the same day as the samples.

During each Verification Test period, one treated water sample shall be analyzed by scanning for the presence and concentration of potential by-products of SOC disinfection by oxidation. Gas chromatography followed by mass spectrometry can be used to identify many of the organic by-products formed during oxidation disinfection. The spectra obtained by this analysis can be matched to a compound library in a computer database to identify the various by-products. This analysis shall be performed by a state-certified or third party- or EPA-

accredited analytical laboratory. The scan should be targeted toward the SOC of interest, and the potential by-products associated with oxidation of that SOC.

Spiked samples shall be analyzed once, at the beginning of each Verification Test Run. The laboratory shall spike a feed water sample with a known quantity of the SOC(s) of interest and analyze this spiked sample. SOC analysis of the spiked sample will indicate if there are any interferences present in the feed water. The broad scan can be a performance-based scan (i.e., the scan is not used for compliance, and therefore undergoes less rigorous QA/QC and is less expensive than a compliance based scan analysis.)

## **14.6 Trip Control**

For tests utilizing spiked SOCs, a replicate or subsample of the spiking solution shall accompany the actual spiking solution from the analytical laboratory. This replicate sample shall undergo all of the processes used on the actual solution including dose preparation, shipping, preparation for spiking, and return to the laboratory for analysis. The trip control samples should show minimal loss of SOC(s). Significant decreases in the SOC concentration of the trip control sample indicates that some step in handling the solution contributed to the reduction in the SOC concentration. The seeding tests must be repeated when significant loss of SOCs in the trip control sample is observed.

## **15.0 TASK 8: COST EVALUATION**

This Plan includes the assessment of costs of verification with the benefits of testing NF membrane processes over a wide range of operating conditions. Therefore, this Plan requires that one set of operating conditions be tested over a 60-day testing period. The equipment Verification Tests will provide information relative to systems, which provide desired results and the cost, associated with the systems. Design parameters are summarized in Table 15.1. These parameters will be used with the equipment Verification Test costs to prepare cost comparisons for Verification Testing purposes.

Capital and operation and maintenance (O & M) costs realized in the equipment Verification Test may be utilized for calculating cost estimates. O & M costs for each system will be determined during the equipment Verification Tests. The equipment costs will vary based on the cost of membrane equipment. The O & M costs that will be recorded and compared during the Verification Test include:

- Labor;
- Electricity;
- Chemical Dosage, and
- Equipment Replacement Frequency.

The capital and O & M costs will vary based on geographic location.

**Table 15.1: Design Parameters for Cost Analysis**

<b>Design Parameter</b>	<b>Specific Utility Values</b>
Raw water feed rate(mgd)	
Total required plant production rate(mgd)	
By-pass flow rate (mgd)	
Membrane flow rate (mgd)	
High/Low plant feedwater temperature (°C)	
Average Flux (gsfd/psi)	
Maximum Flux (gsfd/psi)	
Average cleaning frequency (days)	
High/Low feed TDS (mg/L)	

O & M costs should be provided for each membrane process that is tested. In order to receive the full benefit of the equipment Verification Test Programs, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the Verification Tests. A summary of O & M costs are outlined in Table 15.2.



**Table 15.2: Operations and Maintenance Cost**

Cost Parameter	Specific Values	
Labor rate + fringe (\$/personnel-hour)		
Labor overhead factor (% of labor)		
Number of O&M personnel hours per week		
Electric rate (\$/kWh)		
Membrane replacement frequency (%/year)		
Chemical Dosage (per week)		
O&M cost (\$/Kgal)		
	Dose	Bulk Chemical Cost
Chlorine (Disinfectant)		
Sulfuric acid (Pretreatment)		
Alum (Pretreatment)		
Hydrochloric acid (Pretreatment)		
Scale inhibitor <sup>2</sup> (Pretreatment)		
Caustic (Post-treatment)		
Sodium hydroxide (Membrane cleaning)		
Phosphoric acid (Membrane cleaning)		

<sup>1</sup>Information for cleaning chemicals and pretreatment chemicals (such as alum) should also be provided in this table. For cleaning agents, the concentration of the cleaning solution used to clean the membranes should be reported as the chemical dosed.

<sup>2</sup>Report the product name and manufacturer of the specific scale inhibitor used.

## 16.0 SUGGESTED READING

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## APPENDIX A - SOC HEALTH EFFECTS INFORMATION

**TABLE A.1: Regulated SOCs under Phase II of the SDWA**

PARAMETER	MCLG (mg/L)	MCL (mg/L)	Sources of Drinking Water Contamination	Potential Health Effects
2,4,5-TP (Silvex)	0.05	0.05	Herbicide on crops, right-of-ways, golf courses; canceled in 1982	Liver and kidney damage
2,4-D (Formula 40, Weedar 64)	0.07	0.07	Runoff from herbicide on wheat, corn, range lands, lawns	Liver and kidney damage
Acrylamide	Zero	TT	Polymers used in sewage and wastewater treatment	Cancer, nervous system effects
Alachlor (Lasso)	Zero	0.002	Runoff from herbicide on corn, soybeans, other crops	Cancer
Aldicarb	0.007	0.007	Insecticide on cotton, potatoes, other crops; widely restricted	Nervous system effects
Aldicarb sulfone	0.007	0.007	Biodegradation of Aldicarb	Nervous system effects
Aldicarb sulfoxide	0.007	0.007	Biodegradation of Aldicarb	Nervous system effects
Atrazine	0.003	0.003	Runoff from use as herbicide on corn and non-crop land	Mammary gland tumors
Carbofuran (Furadan 4F)	0.04	0.04	Soil fumigant on corn and cotton; restricted in some areas	Nervous, reproductivity effects
Chlordane	Zero	0.002	Leaching from soil treatment for termites	Cancer
Dibromochloropropane (DBCP, Nemaflow)	Zero	0.0002	Soil fumigant on soybeans, cotton, pineapple, orchards	Cancer
Ethyl benzene	0.7	0.7	Gasoline, insecticides, chemical manufacturing wastes	Liver, kidney, nervous system effects
Ethylene dibromide (EDB, Bromofume)	Zero	0.00005	Leaded gas additives, leaching of soil fumigant	Cancer
Heptachlor (H-34, Heptox)	Zero	0.0004	Leaching of insecticide for termites, very few crops	Cancer
Heptachlor epoxide	Zero	0.0002	Biodegradation of heptachlor	Cancer
Lindane	0.0002	0.0002	Insecticides for cattle, lumber, gardens; restricted in 1983	Liver, kidney, nervous system, immune system and circulatory system effects
Methoxychlor (DMDT, Marlate)	0.04	0.04	Insecticides for fruits, vegetables, alfalfa, livestock, pets	Growth, liver, kidney, and nervous system effects
Pentachlorophenol	Zero	0.001	Wood preservatives, herbicides, cooling tower wastes	Cancer, liver and kidney effects
Polychlorinated biphenyls (PCBs, Aroclor)	Zero	0.0005	Coolant oils from electrical transformers, plasticizers	Cancer
Toxaphene	Zero	0.003	Insecticide on cattle, cotton, soybeans; canceled in 1982	Cancer

**TABLE A.2: Regulated SOC's under Phase V of the SDWA**

<b>PARAMETER</b>	<b>MCLG (mg/L)</b>	<b>MCL (mg/L)</b>	<b>Sources of Drinking Water Contamination</b>	<b>Potential Health Effects</b>
Adipate (diethylhexyl)	0.4	0.4	Synthetic rubber, food packaging, cosmetics	Decreased body weight
Dalapon	0.2	0.2	Herbicides on orchards, beans, coffee, lawns, roads, railways	Liver, kidney effects
Dinoseb	0.007	0.007	Runoff of herbicide from crop and non-crop allocations	Thyroid, reproductive organ damage
Dioxin	Zero	$3 \times 10^{-8}$	Chemical production by-product, impurity in herbicides	Cancer
Diquat	0.02	0.02	Runoff of herbicides on land and aquatic weeds	Liver, kidney, eye effects
Endothall	0.1	0.1	Herbicide on crops and land and aquatic weeds; rapidly degraded	Liver, kidney, gastrointestinal effects
Endrin	0.002	0.002	Pesticides on insects, rodents, birds; restricted since 1980	Liver, kidney, heart damage
Glyphosate	0.7	0.7	Herbicide on grasses, weeds, brush	Liver, kidney damage
Hexachlorobenzene	Zero	0.001	Pesticide production waste by-product	Cancer
Hexachlorocyclopentadiene	0.05	0.05	Pesticide production intermediate	Kidney, stomach damage
Oxamyl (Vydate)	0.2	0.2	Insecticide on apples, potatoes, tomatoes	Kidney damage
Phthalate	Zero	0.006	PVC and other plastics	Cancer
Phenanthrene (PAH)	Zero	0.0002	Coal tar coatings, burning organic matter, volcanoes, fossil fuels	Cancer
Picloram	0.5	0.5	Herbicide on broadleaf and woody plants	Kidney, liver damage
Simazine	0.004	0.004	herbicide on grass sod, some crops, aquatic algae	Cancer

## APPENDIX B – PROPOSED SOCS FOR REGULATION

**TABLE B.1: Proposed SOCs for Regulation**

Parameters	Regulatory Status.	MCLG (mg/L)	MCL (mg/L)	Status HA	RID (mg/kg/day)	DWEL (mg/L)
Acetochlor	---	---	---	---	---	---
Acifluorfen	Tentative	zero	---	Final	0.013	0.4
Acrylonitrile	Tentative	zero	---	Draft	---	---
Aldrin	---	---	---	Draft	0.00003	0.001
Bromobenzene	Listed	---	---	Draft	---	---
Bromomethane	Tentative	---	---	Final	0.001	0.05
Cyanazine	Tentative	0.001	---	Draft	0.002	0.07
Diazinon	---	---	---	Final	0.00009	0.003
Dicamba	Listed	---	---	Final	0.03	1
Dichloroethane (1,1)	---	---	---	---	---	---
Dichloropropane (1,3-)	Listed	---	---	Draft	---	---
Dichloropropane (2,2-)	Listed	---	---	Draft	---	---
Dichloropropene (1,1-)	Listed	---	---	Draft	---	---
Dichloropropene (1,3-)	Tentative	zero	---	Final	0.0003	0.01
Dieldrin	---	---	---	Final	0.00005	0.002
Dinitrophenol (2,4)	---	---	---	---	---	---
Dinitrotoluene (2,4-)	Listed	---	---	Final	0.002	0.1
Dinitrotoluene (2,6-)	Listed	---	---	Final	0.001	0.04
Diphenylhydrazine (1,2)	---	---	---	---	---	---
Disulfoton	---	---	---	Final	0.00004	0.001
Diuron	---	---	---	Final	0.002	0.07
Fonofos	---	---	---	Final	0.002	0.07
Hexachlorobutadiene	Tentative	0.001	---	Final	0.002	0.07
Isopropyltoluene (p-)	---	---	---	---	---	---
Linuron	---	---	---	---	---	---
Methomyl	Listed	---	---	Final	0.025	0.9
Methyl Bromide	---	---	---	---	---	---
Methyl-Phenol (2-)	---	---	---	---	---	---
Methyl tert butyl ether (MTBE)	Listed	---	---	Draft	0.03	1
Metolachlor	Listed	---	---	Final	0.1	3.5
Metribuzin	Listed	---	---	Final	0.013	0.5
Molinate	---	---	---	---	---	---
Naphthalene	---	---	---	Final	0.004	0.1

**TABLE B.1: Proposed SOCs for Regulation (Cont.)**

<b>Parameters</b>	<b>Regulatory Status.</b>	<b>MCLG (mg/L)</b>	<b>MCL (mg/L)</b>	<b>Status HA</b>	<b>RID (mg/kg/day)</b>	<b>DWEL (mg/L)</b>
Nitrobenzene	---	---	---	---	---	---
Organotins	---	---	---	---	---	---
Perchlorate	---	---	---	---	---	---
Prometon	Listed	---	---	Final	0.015	0.5
RDX	---	---	---	Final	0.003	0.1
Terbacil	---	---	---	Final	0.013	0.4
Terbufos	---	---	---	Final	0.00013	0.005
Tetrachoroethane (1,1,2,2-)	Listed	---	---	Draft	---	---
Triazine	---	---	---	---	---	---
Trichlorophenol	Listed	---	---	Draft	---	---
Trichloropropane (1,2,3-)	Listed	---	---	Final	0.006	0.2
Trifluralin	Listed	---	---	Final	0.0075	0.3
Trimethylbenzene (1,2,4-)	---	---	---	Draft	---	---

## Sources:

1. US EPA Office of Water, "Drinking Water Regulations and Health Advisories", EPA-822-B-96-002, October 1996.
2. Federal Register, Volume 62, Number 193, October 6, 1997.